(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 762 326 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
12.03.1997 Bulletin 1997/11

(51) Int. Cl.[6]: G06T 7/00

(21) Application number: 96114009.2

(22) Date of filing: 02.09.1996

(84) Designated Contracting States:
DE FR GB

(30) Priority: 12.09.1995 JP 234019/95
30.11.1995 JP 312677/95

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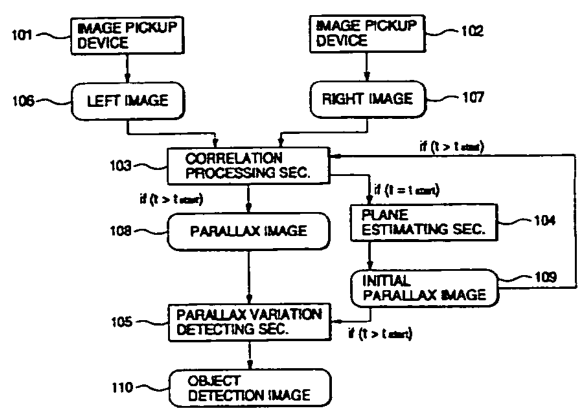
(54) Object detecting apparatus in which the position of a planar object is estimated by using hough transform

(57) Based on left and right images that have been taken by image pickup devices, a correlation processing section obtains parallax data as three-dimensional data of objects. At processing start time, a plane estimating section estimates the position of a planar object such as a road or a floor by utilizing the Hough transform based on the parallax data that have been obtained successfully for part of rectangular segments of the images, and interpolates the parallax data by using the position of the planar object. At a time point after the processing start time, a parallax variation detecting section detects an object by comparing current parallax data with the parallax data at the processing start time.

FIG. 1



EP 0 762 326 A2

Printed by Rank Xerox (UK) Business Services
2.13 16/3.4

BNSDOCID: <EP _ 0762326A2 I >

t_{START} is called an initial parallax image, to distinguish it from a parallax image at time t (> t_{START}).

By comparing parallaxes of the same block 302 of a parallax image at time t (present time) and that at time t_{START} (past time), a parallax variation detecting section 204 judges that a new object has appeared or an object has disappeared in a block 302 with which a parallax variation larger than a given threshold has occurred.

Now, the Hough transform will be described with reference to Fig. 5. A straight line 501 on the x-y plane is expressed as

$$\rho_0 = x\cos\theta_0 + y\sin\theta_0 \qquad (4)$$

where ρ_0 is the length of a perpendicular 502 dropped from the origin O toward the straight line 501 and θ_0 is an angle formed by the perpendicular 502 and the x axis.

Equation (5) is defined for each of a series of points (x_i, y_i), i = 0, 1, 2, ... on the x-y plane:

$$\rho = x_i\cos\theta + y_i\sin\theta \qquad (5)$$

On the ρ-θ plane, Equation (6) is expressed as a composite sinusoidal function called a Hough curve as shown in Fig. 6, and represents every straight line passing through the point (x_i, y_i). Where the points (x_i, y_i) are approximately located on a straight line, their Hough curves on the ρ-θ plane cross each other in the vicinity of a single point 601 as shown in Fig. 6. The straight line on the x-y plane (see Equation (4)) is determined by point 601 (ρ_0, θ_0) where most Hough curves cross each other. The above operation is called straight line fitting by the Hough transform. Since the straight line fitting by the Hough transform is a straight line detecting method with recognition of a general tendency of a series of data points, a straight line can be detected even if the data points include points that are not located on that line.

The above object detecting apparatus is required to be able to correctly estimate the position, in a three-dimensional space, of a relatively large planar object such as a road, a floor, or a wall which is to serve as a reference for object detection judgment.

In the above object detecting apparatus, when rectangular segments of left and right images 301 and 401 are correlated with each other by the correlation processing section 203, a segment of the right image 401 which makes the similarity evaluation value C smallest is employed as a corresponding segment. However, there may occur a case that because of a small number of features, a segment that makes the similarity evaluation value C smallest cannot be obtained clearly for part of blocks 302 of a planar object and hence parallax data cannot be calculated therefor. This means that the object detecting apparatus cannot perform correct detection which apparatus operates on the assumption that parallax data are obtained almost completely in initial and current parallax images.

Further, in the convention correlation processing, a parallax-related distance measurement range 703 (see Fig. 7) is set in consideration of an object closest to and an object most distant from image pickup devices 702, and is fixed irrespective of the position in an image. However, in almost all cases, an object to be detected is located closer to the image pickup devices 702 than a plane object 701 such as a road, a floor, or a wall is, and the plane object 701 does not extend perpendicularly to the optical axes of the image pickup devices 701. This means that the amount of calculation is unduly large in the conventional technique because the parallax determination is performed in vain in a range which includes no object for distance measurement.

SUMMARY OF THE INVENTION

A first object of the present invention is to correctly estimate a three-dimensional position of a planar object by a global straight line approximation technique utilizing the Hough transform, without being affected by objects other than the planar object.

A second object of the invention is to perform object detection with high accuracy by estimating the position of a planar object and inserting proper data for undetermined parallax data of the same plane object by interpolation.

A third object of the invention is to reduce the amount of correlation calculation by optimizing the parallax determination range for each block position of an image based on information of an estimated position of a plane object.

To attain the above objects, the invention has a general feature that the position of a planar object is estimated by Hough transform processing based on successfully measured parallel data.

According to a first aspect of the invention, there is provided an object detecting apparatus comprising:

a plurality of image pickup means disposed at a predetermined interval, for producing a plurality of images;
a correlation processing section for producing three-dimensional data of objects according to triangulation through correlation between the plurality of images; and
a plane estimating section for estimating a position of a planar object in a three-dimensional space by performing Hough transform on the three-dimensional data.

mined ones of the same planar object through an interpolating operation by using the estimated position of the planar object. As a result, an object that is distant from the planar object can be detected more accurately.

According to still another aspect of the invention, there is provided an object detecting apparatus comprising:

a plurality of image pickup means disposed at a predetermined interval, for producing a plurality of images;
means for estimating a position of a planar object in a three-dimensional space based on the plurality of images; and
means for producing three-dimensional data of an object except for an object that is more distant from the plurality of image pickup means than the planar object is.

With this configuration, the amount of correlation calculation can be reduced because three-dimensional data is not measured for an object that is more distant from the image pickup devices than a planar object such as a road, a floor, or a wall is.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow diagram showing the configuration of an object detecting apparatus having a plane estimating section according to a first or third embodiment of the present invention;
Fig. 2 is a flow diagram showing the configuration of a conventional object detecting apparatus;
Fig. 3 illustrates how blocks are arranged in a left image, i.e., reference image;
Fig. 4 illustrates a parallax search area of a right image in the conventional technique;
Fig. 5 shows straight line parameters used for the Hough transform;
Fig. 6 shows an example of Hough curves;
Fig. 7 illustrates a general positional relationship between image pickup devices and a planar object;
Fig. 8 is a flowchart showing a plane estimating scheme according to a second embodiment of the invention;
Fig. 9 shows a three-dimensional reference coordinate system used in the second embodiment;
Fig. 10 shows fitting of a plane passage straight line in the second embodiment;
Fig. 11 illustrates straight line approximation with the Hough transform in the second embodiment;
Fig. 12 shows a result of step 801 of the plane estimating scheme according to the second embodiment;
Fig. 13 shows a result of step 802 of the plane estimating scheme according to the second embodiment;
Fig. 14 shows a distance correction line in the second embodiment;
Fig. 15 shows fitting of the distance correction line in the second embodiment of the invention; and
Fig. 16 shows a result of step 803 of the plane estimating scheme according to the second embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be hereinafter described with reference to the accompanying drawings.

Embodiment 1

Fig. 1 shows the configuration of an object detecting apparatus according this embodiment. In this object detecting apparatus, of left and right images 106 and 107 taken by image pickup devices 101 and 102, the left image 106 is divided into M (horizontal) x N (vertical) blocks. A correlation processing section 103 acquires a parallax S(X, Y) as three-dimensional data of an object on a block-by-block basis. A plane estimating section 104 estimates the position of a planar object by using parallaxes successfully measured by the plane estimating section 104. A parallax variation detecting section 105 extracts a block with which the parallax of a parallax image 108 at time t has varied from that of an initial parallax image 109 at processing start time t_{START} (< t) by more than a threshold TH, and judges that there exists a new object at a position indicated by the block.

The operation of the object detecting apparatus having the above configuration will be described with reference to Fig. 1. Separate descriptions will be made of a stage where images are input at processing start time t_{START} and a stage where images are input at time t (> t_{START}).

At the first stage, images taken at time t_{START} are input to the correlation processing section 103, where the left and right images 106 and 107 are correlated with each other and information of positional deviations between the images 106 and 107, that is, parallaxes S are produced. The parallax is a kind of three-dimensional data. The parallaxes S(X, Y) of respective blocks obtained by dividing the left image 106 are input to the plane estimating section 104, which estimates the position of a plane object in the real space by using successfully measured parallaxes S(X, Y), and outputs an initial parallax image 109 including the parallaxes S(X, Y) of the respective blocks. Further, the plane estimating section 104 performs interpolation to produce parallaxes for blocks with which the parallax measurement failed in the above attempt.

$\rho_E(Y)$, they are written as

$$\theta_K(Y) = \theta_R + \theta_E(Y) \tag{8}$$

$$\rho_K(Y) = \rho_R(Y) + \rho_E(Y)$$

where θ_R and $\rho_R(Y)$ are their highly reliable values. That is, at the present stage the plane passage straight lines not necessarily exist on the same plane, and this will be corrected by the following operations.

[Step 802: Correction of slopes of plane passage straight lines]

If all the plane passage straight line existed on the same plane, the angles $\theta_K(Y)$ formed by the perpendiculars to the Y axis (projections onto the S-X plane) of all the straight lines and the X axis should have the same value. Therefore, a center value θ_R is determined by sorting magnitudes of the angles $\theta_K(Y)$, and all the angles $\theta_K(Y)$ are replaced by the center value θ_R. Thus, the angles $\theta_K(Y)$ formed by the perpendiculars of the respective plane passage straight lines and the X axis are now represented by the most reliable slope angle θ_R. Stated in terms of formulae, Equation (9) corresponds to the case where the angles $\theta_K(Y)$ of the respective plane passage straight lines include the error components $\theta_E(Y)$, and Equation (10) corresponds to the case where the error components $\theta_E(Y)$ are removed from the angles $\theta_K(Y)$ of all the straight lines by replacing the angles $\theta_K(Y)$ with the most reliable angle θ_R.

$$S(X, Y) = -\frac{\cos(\theta_R+\theta_E(Y))}{\sin(\theta_R+\theta_E(Y))} X + \frac{\rho_R+\rho_E(Y)}{\sin(\theta_R+\theta_E(Y))} \tag{9}$$

$$S(X, Y) = -\frac{\cos\theta_R}{\sin\theta_R} X + \frac{\rho_R+\rho_E(Y)}{\sin\theta_R} \tag{10}$$

As a result of the above operation, the slopes of the plane passage straight lines, which were different from the slope of the plane as defined by the angle of a perpendicular to the Y axis, are now corrected. At the present stage, all the plane passage straight lines have the same slope as shown in Fig. 13 in which they are drawn in the S-X-Y reference coordinate space.

[Step 803: Distance correction of plane passage straight lines]

Where there exist two non-parallel planes in a three-dimensional space, they should have a straight crossing line. Based on this fact, as shown in Fig. 14, a straight line formed by a plane 1401 to be estimated and a Y-ρ_K plane 1402 is determined by utilizing the Hough transform. The ρ_K axis is an axis that is inclined from the X-axis by θ_R. Distances $\rho_K(Y)$ from the Y axis of the respective straight lines are plotted on the Y-ρ_K plane as shown in Fig. 15. Plotted points (Y, ρ_K) on the Y-ρ_K plane are subjected to the Hough transform according to Equation (11).

$$\rho' = Y\cos\theta' + \rho_K(Y)\sin\theta',\ \theta'_{start} \le \theta' \le \theta'_{end} \tag{11}$$

After a point (ρ'_S, θ'_S) where most Hough curves cross each other on the ρ'-θ' plane is found, a straight line 1501 is determined by using Equation (11). Since the straight line 1501 indicates distances from the Y axis which are considered most suitable for the respective plane passage straight lines, it is called a distance correction line. In Fig. 14, the distance correction line is denoted by numeral 1403. The distance correction line is expressed as

$$\rho_R(Y) = -\frac{\cos\theta'_S}{\sin\theta'_S} Y + \frac{\rho'(Y)}{\sin\theta'_S} \tag{12}$$

By correcting the distances $\rho_K(Y)$ from the Y axis of the respective plane passage straight lines into $\rho_R(Y)$ by using the distance correction line 1403, Equation (10) is changed to

receiving a plurality of images that are produced by a plurality of image pickup means disposed at a predetermined interval;

calculating three-dimensional data $S(X, Y)$; $1 \leq X \leq M$, $1 \leq Y \leq N$ for each of rectangular segments obtained by dividing the received images into M parts in a horizontal direction and into N parts in a vertical direction through correlation between the received images;

determining a plane passage straight line $L(Y)$ by performing Hough transform on M three-dimensional data corresponding to rectangular segments belonging to a horizontal area $GL(Y)$ of the received images;

performing the determining step on all horizontal areas $GL(Y)$, $1 \leq Y \leq N$, to thereby determine N plane passage straight lines $L(Y)$, $1 \leq Y \leq N$; and

estimating a position of a planar object in a three-dimensional space based on the N plane passage straight lines $L(Y)$, $1 \leq Y \leq N$.

3. The plane estimating method according to claim 2, further comprising the steps of:

calculating an angle $\theta(Y)$ of a perpendicular to both of a Y axis and each of the N plane passage straight lines $L(Y)$, $1 \leq Y \leq N$, to obtain N angles $\theta(Y)$, $1 \leq Y \leq N$;

calculating a central angle value θ_R of the N angles $\theta(Y)$, $1 \leq Y \leq N$; and

replacing all of the angles $\theta(Y)$, $1 \leq Y \leq N$ with the central angle value θ_R, to obtain N angle-corrected plane passage straight lines $L'(Y)$, $1 \leq Y \leq N$,

wherein the estimating step estimates the position of the planar object based on the N angle-corrected plane passage straight lines $L'(Y)$, $1 \leq Y \leq N$.

4. The plane estimating method according to claim 3, further comprising the steps of:

calculating a distance $\rho(Y)$ between the origin of a coordinate system of the three-dimensional data $S(X, Y)$ and each of the N angle-corrected plane passage straight lines $L'(Y)$, $1 \leq Y \leq N$, to obtain N distances $\rho(Y)$, $1 \leq Y \leq N$;

determining a distance correction line by performing Hough transform on the N distances $\rho(Y)$, $1 \leq Y \leq N$; and

translating the N angle-corrected plane passage straight lines $L'(Y)$, $1 \leq Y \leq N$ so that they intersect the distance correction line, to obtain N distance-corrected plane passage straight lines $L''(Y)$, $1 \leq Y \leq N$,

wherein the estimating step estimates the position of the planar object based on the N distance-corrected plane passage straight lines $L''(Y)$, $1 \leq Y \leq N$.

5. An object detecting apparatus comprising:

a plurality of image pickup means disposed at a predetermined interval, for producing a plurality of images;

means for producing three-dimensional data of objects for respective rectangular segments of the plurality of images;

a plane estimating section for estimating a position of a planar object in a three-dimensional space based on the three-dimensional data;

means for producing, by using the position of the planar object, three-dimensional data for part of the rectangular segments for which three-dimensional data could not be produced, to obtain interpolated three-dimensional data; and

means for detecting an object that is located at a position different than the planar object when viewed from the plurality of image pickup means based on the interpolated three-dimensional data.

6. An object detecting apparatus comprising:

a plurality of image pickup means disposed at a predetermined interval, for producing a plurality of images;

means for estimating a position of a planar object in a three-dimensional space based on the plurality of images; and

means for producing three-dimensional data of an object except for an object that is more distant from the plurality of image pickup means than the planar object is.

FIG. 2
PRIOR ART

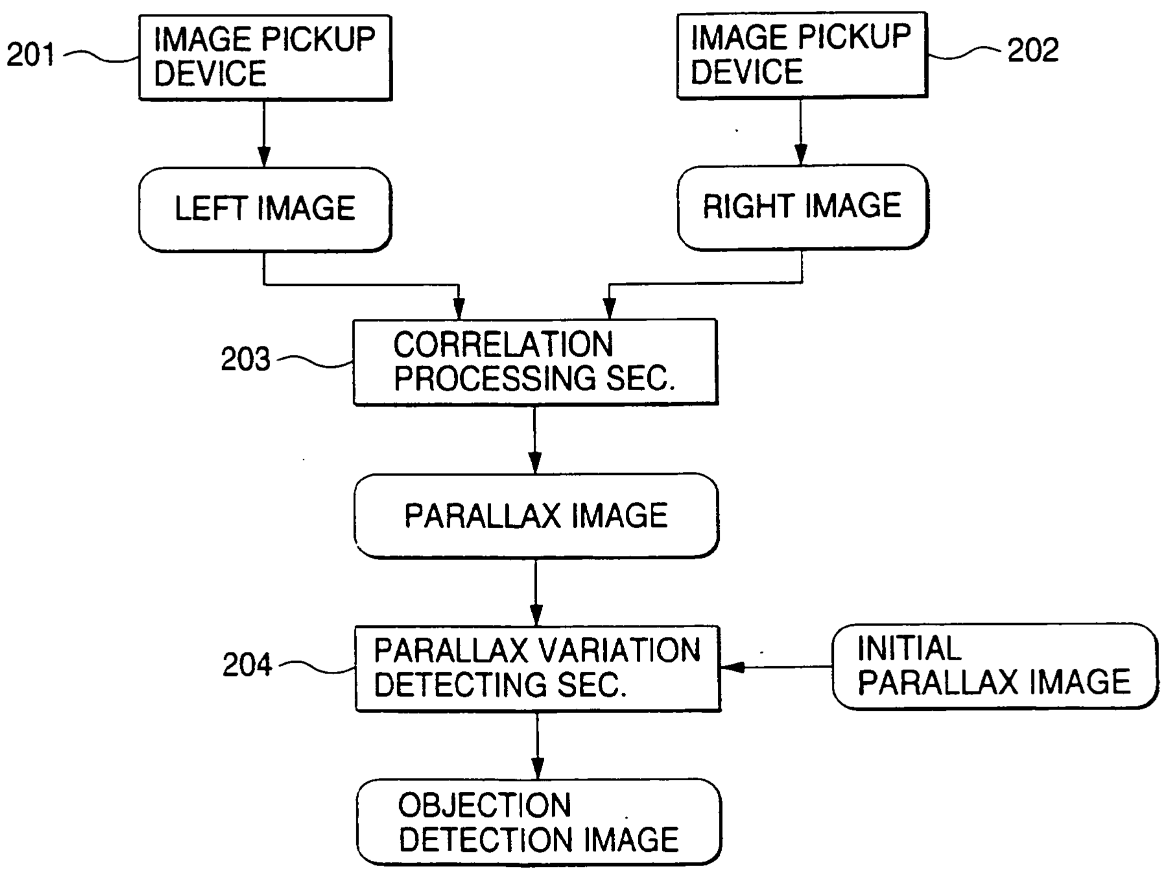


FIG. 5
PRIOR ART

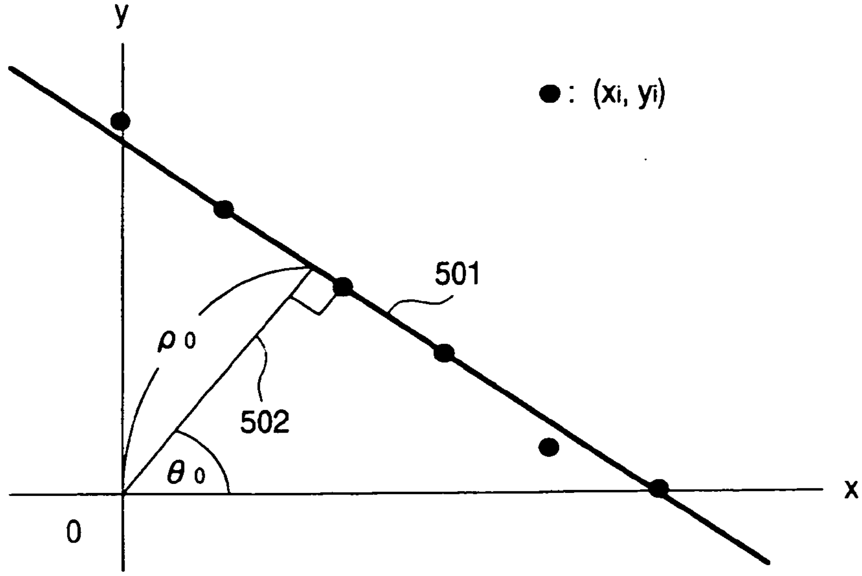


FIG. 6
PRIOR ART

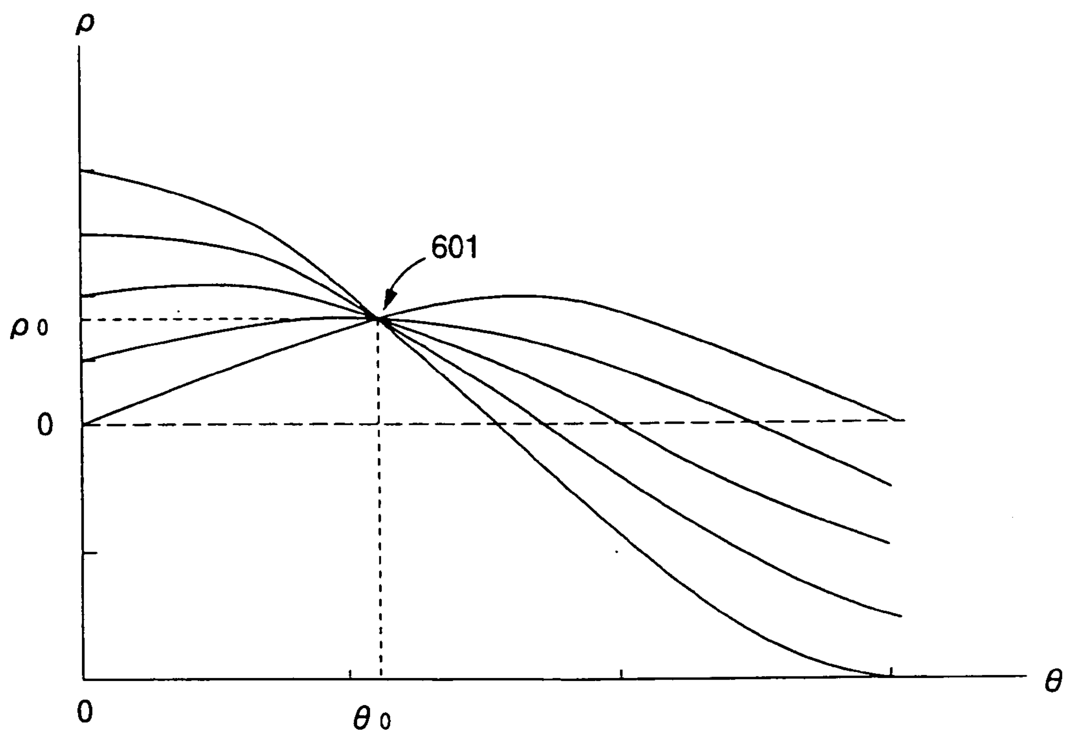


FIG. 9

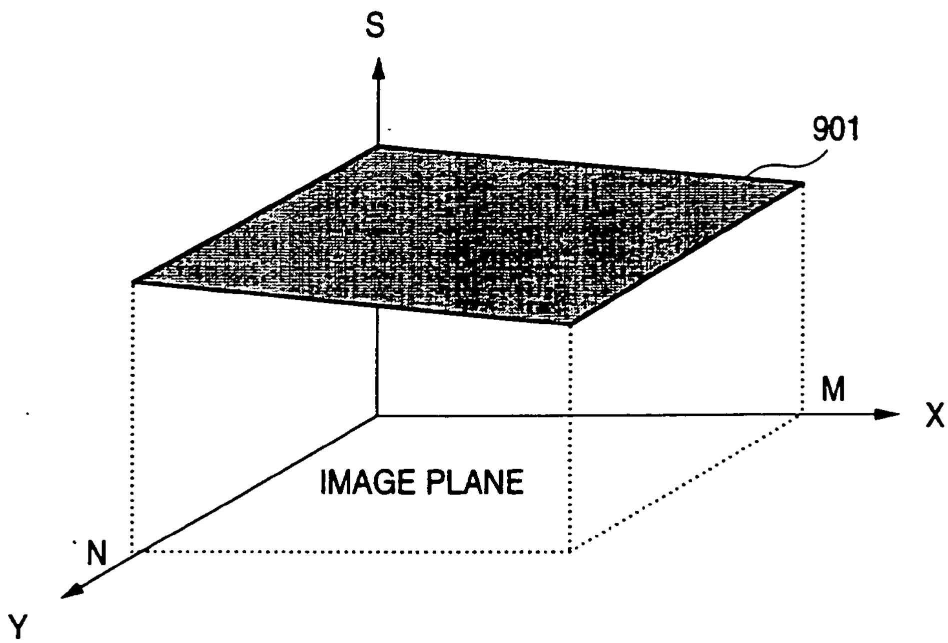

S
901
M
X
IMAGE PLANE
N
Y

FIG. 10

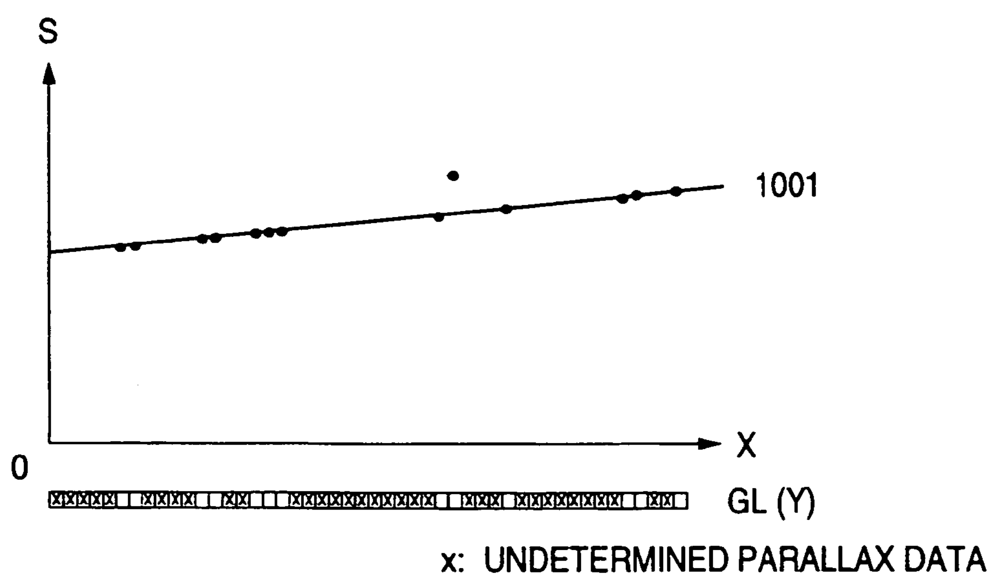

S
1001
X
0
GL (Y)
x: UNDETERMINED PARALLAX DATA

FIG. 13

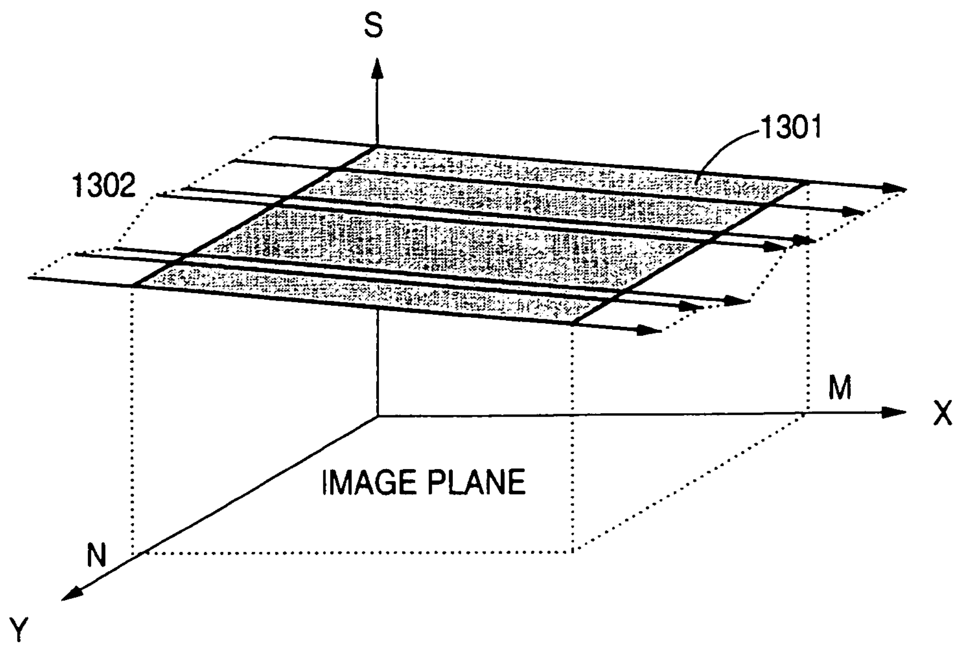
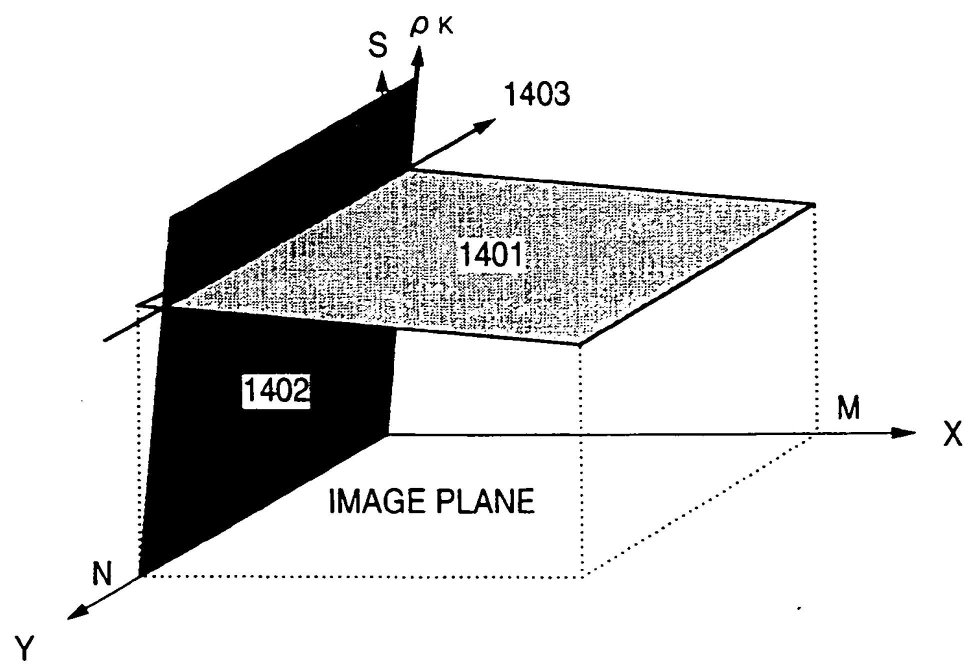

S
1301
1302
M
X
IMAGE PLANE
N
Y

FIG. 14


S
ρ K
1403
1401
1402
M
X
IMAGE PLANE
N
Y

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(11) EP 0 762 326 A3

(12) **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:
10.09.1997 Bulletin 1997/37

(43) Date of publication A2:
12.03.1997 Bulletin 1997/11

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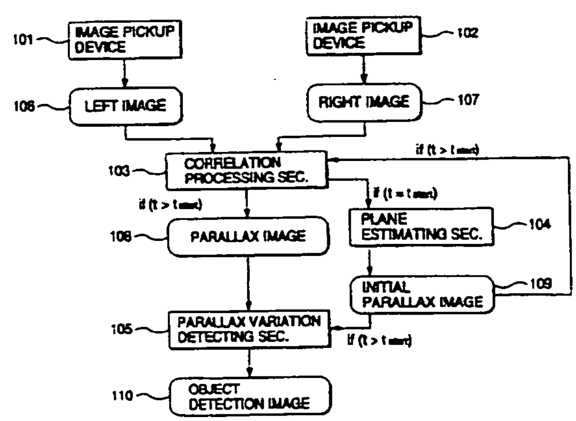
FIG. 1.



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